What Drives University Technological Innovation and Commercialization?

Full Paper

Benjamin Yeo
DePaul University
benjkyeo@gmail.com

Abstract

Universities are a source of technological innovation, which in turn facilitates economic growth. The Bayh-Dole Act of 1980 was enacted to support university research efforts. However, since its enactment, university technological innovation had been increasing slowly. In this study, I explore the current and future impact of university characteristics and regional industry R&D activities on university technological innovation and commercialization. The findings verify existing, albeit fairly dated, literature by demonstrating their current impact; and extend it by showing their future impact to various degrees. The intricacies of the coefficients of impact enrich our understanding of how these drivers can be leveraged to boost university innovation and technology commercialization.

Keywords

Technology transfer, university research, technological innovation, patents

Introduction

In the U.S., universities provide higher education, research, and public services (Rhoten & Calhoun, 2011). University research and development (R&D) activities, are important sources of innovation that can be commercialized (Ho, Liu, Lu, & Huang, 2014). Mansfield (1991) found that between the 1960s and 1970s, investments in academic research experienced a high social rate of return. In light of this importance, among other reasons, the Bayh-Dole Act of 1980 was enacted to support university research efforts by permitting universities to claim ownership of their innovation (Ho et al., 2014), thereby spurring a growth in university patents and licensing (Mowery & Sampat, 2005).

However, increases in successfully commercialized university innovation had been slow. Licensing income generated were found to be less than 3% of university research expenditures in 1995 and 2004 (Swamidass & Vulasa, 2009). Incidentally, the impact of technological innovations may experience lags (Kauffman & Weill, 1989; Oz, 2005; Stiroh, 2002). Taken together, these possibly reinforce the skepticism surrounding the role of universities as a driving force for regional economic growth (Florida, 1999).

It is therefore, imperative to investigate the drivers of university innovation and technology commercialization. This study represents an extension of the literature by exploring the impact of both university and regional characteristics on current and future impact. The findings can justify future renditions of regional science and innovation policies to support university R&D, thus boosting the intended consequences of the Bayh-Dole Act. This will also augment the role of universities as foci of regional technological innovation in high technology industry clusters, developing industry linkages and increasing both academic and industry scientific R&D and engineering. To this end, the objective of the study is to identify factors that drive U.S. university innovation and technology commercialization.

Literature Review

University Innovation and Commercialization

Technological innovation is a third endogenous factor, beyond labor and capital that can explain economic growth (Romer, 1990). This remains important today (European Commission, 2008, p. 200; OECD, 2013), and economic sustainability relies "very heavily upon an economy's scientific and technological sophistication, which in turn is dependent upon R&D capabilities," (European Commission, 2008, p. 12). Universities are a source of revenue and regional economic growth (Friedman & Silberman, 2003). Through technology transfers, results from university R&D (i.e. university innovation) are licensed for commercialization and further development (Bauer & Flagg, 2010; Friedman & Silberman, 2003). Commercialization involves licensing the innovation or launching start up companies (Hsu, Shen, Yuan, & Chou, 2015). MIT and Stanford University are exemplars in this respect. They triggered the growth of high technology clusters in Route 128 and Silicon Valley respectively (Swamidass & Vulasa, 2009). The pools of skilled labor encourages businesses to locate their operations in close proximity, so as to gain access to talented individuals (Florida, Gates, Knudsen, & Stolarik, 2006). Companies in these clusters leverage knowledge spillovers and accumulation, resulting in higher economic productivity compared to companies outside them (DeVol, Lee, & Ratnatunga, 2016).

The strength of university innovation output can be operationalized by the number of applied or awarded patents (Anderson, Daim, & Lavoie, 2007; Ion & Cristina, 2014; D. S. Siegel, Veugelers, & Wright, 2007); and its level of commercialization can be operationalized by licensing income (Friedman & Silberman, 2003), and university start up formation, or spin offs firms (Hsu et al., 2015; D. S. Siegel & Phan, 2005; Thursby & Kemp, 2002). Pertaining to the latter, start up firms enable universities to disseminate their innovation beyond the academia (Siegel & Phan, 2005; Thursby & Kemp, 2002, p. 2002); and in so-doing, they form the impetus for regional high technology clusters and hence, economic growth.

Internally, universities themselves play critical roles in the technology transfer process (Ho et al., 2014), implying that university characteristics that are related to R&D can influence innovation outcomes and commercialization. Among these characteristics, financial resources, in the form of government funding (Foltz, Barham, & Kim, 2000; O'Shea, Allen, Chevalier, & Roche, 2005), and operationalized by R&D expenditure (Chapple, Lockett, Siegel, & Wright, 2005; Lockett & Wright, 2005; Powers & McDougall, 2005; Siegel, Waldman, & Link, 2003), can support university technology transfers (D. Siegel, Wright, Chapple, & Lockett, 2008; Thursby & Thursby, 2002). Powers and McDougall (2005) demonstrated the positive impact of R&D expenditure on the commercialization of university innovation, which includes start up companies. Similarly, Carlsson and Fridh (2002) found that research expenditures positively influence successful university technology transfers.

By supporting university researchers' R&D activities, these funds facilitate the development of innovation output for commercialization (Friedman & Silberman, 2003; Lach & Schankerman, 2004; Rogers, Yin, & Hoffmann, 2000; Thursby & Kemp, 2002, p. 2002). Furthermore, the level of industry funding also positively influences the amount of licensing activities and formation of university spin off companies (Friedman & Silberman, 2003; Lach & Schankerman, 2004; Link & Siegel, 2005; Rogers et al., 2000; Thursby & Kemp, 2002). The relevance of industry support in the form of business expertise may help support the launch of start up companies (Wright, Vohora, & Lockett, 2004). These findings warrant the inclusion of both university Federal and industry R&D expenditure as separate variables for analysis.

Studies have also shown that university R&D are geographically concentrated (Chapple et al., 2005; Friedman & Silberman, 2003; Mathews & Hu, 2007), with universities serving as an incubator for entrepreneurship and start up companies (Hsu et al., 2015). Friedman and Silberman (2003) found that a university's proximity to high technology firms and experience of their technology transfer offices can enhance their technology transfers, and this was not heavily examined previously in the literature. Similarly in the same year, Siegel et. al. (2003) found that states that have higher levels of industry R&D activities have more efficient universities. Along the same lines, access to industry-based researchers can positively influence the university's capabilities to generate licenses and income (Friedman & Silberman, 2003; O'Shea et al., 2005). These suggest that the proximity of a university to a high technology cluster is indirectly influential to its R&D activities. In addition, given the relevance of human capital in successful technology transfers (Hsu et al., 2015), it is therefore, reasonable to use the concentration of industry R&D professionals to operationalize the regional concentration of high technology industry activities.

The speed at which universities can commercialize technological innovation is a facilitator of licensing revenue and new ventures (Markman, Gianiodis, Phan, & Balkin, 2005). This speed can be the result of efficient technology transfer offices that are responsible for commercializing it through licensing or start ups (Hsu et al., 2015; Siegel et al., 2003). The number of staff supporting technology transfers (or the size of technology transfer offices) was found to positively influence the success of the transfers (Chang, Chen, Hua, & Yang, 2006; Foltz et al., 2000; Lach & Schankerman, 2004; Link & Siegel, 2005; Rogers et al., 2000; Thursby, Jensen, & Thursby, 2001). University staff supporting technology transfers go beyond those who are who are directly involved in licensing and patenting. Others working in the technology transfer offices, including professional or administrative staff are also important in facilitating the process. Therefore, it is reasonable to include both types of staff as separate variables in the investigation.

Theoretical Gaps and Research Question

From the preceding discussion, there are two theoretical gaps in the literature that support the proposed investigation. First, while predictive analyses on the drivers of university innovation and commercialization have been done, previous studies have not looked at both university characteristics and regional industry R&D activities as potential drivers at the same time. Given the relevance of various university characteristics such as R&D expenditure and staff, as well as proximity to high technology industry activities, it is paramount to explore both sets of factors simultaneously. Second, impact phenomena may experience lags, and such lags can be included in investigations on the impact of technologies (Kauffman & Weill, 1989; Oz, 2005; Stiroh, 2002). In the case of university innovation, there may be a period of learning and adjustment that delays the direct impact (Brynjolfsson & Yang, 1996). Hence, in the predictive analyses, I included measurements of both current and future impact.

This study represents an extension and enrichment of the literature by revisiting similar analyses. A majority of these studies on the drivers of university innovation and commercialization have been done on or prior to 2010. This revisit will provide an update and verification to the existing literature, as well as serve as an impetus for future research that enhances our understanding. From the preceding discussion, I seek to address the following primary research question: What university characteristics and regional industry R&D activities drive current and future university innovation and technology commercialization?

Method

The study looks at the current (i.e. direct) and future (i.e. lagged) impact of university characteristics and regional R&D activities on university innovation and commercialization. The former refers to inputs that support university's R&D and their technology transfer processes, while the latter comprises the university's proximity to R&D activities in the region. Current impact looks at the innovation output and results of technology commercialization from each university, in each specific year, while future impact looks at the same dependent variables one succeeding year from the recorded year. These constructs are summarized in Figure 1.

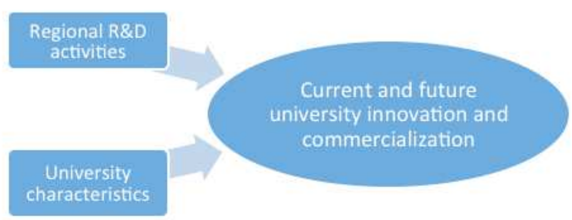

Figure 1. Research Framework

The analyses were conducted using secondary university patent data from the Association of University Technology Managers (AUTM) survey. It includes data on U.S. universities from 1991 to 2014. The constructs were operationalized using several variables highlighted in Table 1. Following the literature review, the university characteristics that have been argued to influence university innovation output are financial support from the government and the industry, and university staff support in technology transfer. These are operationalized by both Federal and industry R&D expenditures, full time technology transfer employees who are directly involved in the licensing and patenting processes, as well as other employees who have professional or administrative responsibilities related to technology transfer at the university. Without exact numbers of the Federal and industry research grants received by each university in each year, the corresponding research expenditures serve as surrogates that reflect how much of the research grants have been spent.

The literature also shows that proximity to high technology firms positively influences university innovation. Close proximity to high technology firms reflects a higher regional concentration of high tech activities, which in turn reflects industry R&D activities. To include this as a variable, the concentration of industry R&D activities was measured by the location quotient (LQ) of industry R&D employees in the state. The location quotient is a measure of the ratio of the proportion of R&D professionals in the state to the same proportion in the U.S. A value of higher than 1.0 shows that the region has a higher concentration of industry R&D professionals compared to the U.S. on average, and therefore, the region (or state in this case) has a specialty in industry R&D activities. A value of less than 1.0 reflects otherwise (Leigh, 1970). The definition of industry R&D professionals follows the Scientific Research and Development Services Industry definition by the North American Industry Classification System (NAICS) provided by the Bureau of Labor Statistics (BLS). This measure shows the strength of concentration of (and hence proximity to) high technology firms for each university. Due to resource limitations, I was not able to compute this at the county or metropolitan statistical area (MSA) level where each university is located. I discuss this as a limitation in the Conclusion.

Using the AUTM data set, four variables – licensing income, patents applied, patents issued, and university start ups formed – were used to measure university innovation and commercialization. These are consistent with previous studies. Patents filed and issued refers to the innovation resulting from university R&D. Licensing income and university start ups are the result of successful technology transfers and hence, commercialization. Current and subsequent year measurements of these four variables were used as a proxy for current and future impact respectively. The methods of analysis include descriptive statistics that provide a summary of the variables investigated, and regression analyses to determine the impact of each independent variable in current and future innovation output and commercialization. Regression analyses have been used in studies on university technology transfers (Carlsson & Fridh, 2002; Thursby et al., 2001).

Variables	Operationalization
University characteristics	• Federal R&D expenditure • Industry R&D expenditure • Full time tech transfer employees • Other (support) full time employees
Regional R&D activities	• Regional concentration of R&D professionals
Direct university innovation output	• Licensing income in current year • Patents applied in current year • Patents awarded in current year • University start up firms in current year
Future university innovation output	• Patents applied in subsequent year • Patents awarded in subsequent year • Licensing revenue in subsequent year • University start up firms in subsequent year

Table 1. Summary of Variables

Findings

Descriptive Statistics

Table 2 provides a summary of the variables in this study. Universities on average over the entire period have received much more R&D funds from Federal sources than the industry. Technology transfer offices have on average, similar numbers of licensing employees and other support staff.

Var	N	Min	Max	Mean	SD
LicFTE	3782	0.00	95.00	4.26	6.17
OthFTE	3613	0.00	103.00	4.43	8.18
LQ	3936	0.07	7.55	1.08	0.95
FedRes	3803	$0.00	$2,978,256,026.00	$145,877,559.02	222839038.68
IndRes	3743	$0.00	$362,497,413.00	$17,485,060.28	31589117.13
Inc	3902	$0.00	$824,426,230.00	$9,096,855.79	32648693.86
PatApp	3873	0.00	1691.00	74.12	117.57
PatIss	3705	0.00	371.00	20.26	31.87
Start	3539	0.00	75.00	2.73	4.43

LicFTE: Licensing full time employees, OthFTE: Other full time employees, LQ: R&D industry activity concentration, FedRes: Federal research expenditure, IndRes: Industry research expenditure, Inc: Licensing income, PatApp: Patents applied, PatIss: Patents issued, Start: Start ups formed.

Table 2. Summary Statistics

The trends of the variables from 1991 to 2014 are given in Figure 2. The gaps in the graphs are the result of missing data. From the left graph, there has been a consistent increase in the sizes of university technology transfer offices. However, the amount of industry R&D activities and research expenditures remained largely the same throughout the period. From the right, there is a general consistency in the other dependent variables throughout the period.

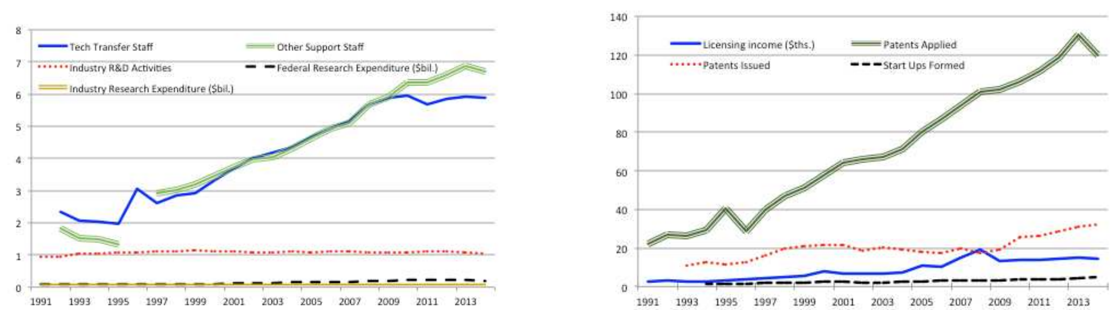

Figure 2. Annual Trends

Taken together, these suggest that universities are actively pursuing innovation output and technology commercialization. However, support from government and industry funding has not increased, and results have not been reflective of their efforts. The consistency in the concentration of industry R&D activities over the period is expected, as regions do not change their economic industry bases easily. Universities spent much more Federal research money than industry research. Consistent with earlier findings (Swamidass & Vulasa, 2009), the yearly average Federal and industry research expenditures across the 24 periods (1991 to 2014) was $141 million and $17 million per year respectively, but yearly licensing income only averaged at $8 million. This means that the returns on investment were 6.09% and 50.57% respectively. Thus, it appears that industry research support generates higher returns.

Predictive Analyses

Eight OLS regression models were built on each of the eight dependent variables, comprising four current impact variables – licensing income, patents applied, patents issued, and start ups formed – and four future impact variables, which refer to the same current impact variables but in their respective subsequent years. The data set posed a limitation for the future impact analysis because it is not a perfectly balanced time series. Not every university has the same representation for all the different years. Part of the reason could be attributed to a lack of innovation activities in any one particular year and/or the participation of a university in the survey. Hence, the sample sizes for current impact analyses were different from future impact. In each model, the natural log of all variables was used to satisfy the assumptions required for OLS regression. The use of the log transformation was used because the theoretical production functions (such as the Cobb-Douglas production function) used in technology and productivity research are exponential. The results are given in Table 4. Generally, all models showed significant findings. However, the significant predictors differed slightly between the current impact, and the future impact (i.e. impact in the subsequent year) for licensing income.

DepVar	R^2	N	Log LicFTE	Log OthFTE	Log LQ	Log FedRes	Log IndRes
			β	β	β	β	β
Log Inc	0.519	3001	0.422**	0.102**	0.008	0.235**	0.022
Log PatApp	0.745	3010	0.299**	0.269**	0.052**	0.289**	0.094**
Log PatIss	0.618	2855	0.226**	0.223**	0.035**	0.268**	0.166**
Log Start	0.396	2072	0.174**	0.208**	-0.020	0.198**	0.138**
Log Inc1	0.506	2571	0.419**	0.091**	0.006	0.227**	0.038*
Log PatApp1	0.737	2574	0.285**	0.266**	0.046**	0.300**	0.097**
Log PatIss1	0.605	2510	0.218**	0.217**	0.046**	0.269**	0.167**
Log Start1	0.418	1872	0.152**	0.240**	-0.028	0.205**	0.143**

* significant at 95% confidence interval, ** significant at 99% confidence interval.

Log Inc: Natural log of licensing income, Log PatApp: Natural log of patents applied, Log PatIss: Natural log of patents issued, Log Start: Natural log of start ups formed, Log Inc1: Natural log of licensing income in the following year, Log PatApp1: Natural log of patents applied in the following year, Log PatIss1: Natural log of patents applied in the following year, Log Start1: Natural log of start ups formed in the following year, Log LicFTE: Natural log of licensing full time employees, Log OthFTE: Natural log of other full time employees, Log LQ: Natural log of R&D industry activity concentration, Log FedRes: Natural log of Federal research expenditure, Log IndRes: Natural log of industry research expenditure.

Table 3. Regression Analyses

Licensing Income

The independent variables predicted a good proportion of variance in current and future licensing income (R^2 = 0.519, F = 646.264, p < 0.001, N = 3001; and R^2 = 0.506, F = 526.172, p < 0.001, N = 2571 respectively). Pertaining to their current impact, the number of full time technology transfer staff, other full time support staff, and the amount of Federal research expenditures were significant predictors at 99% confidence interval (β = 0.422, p < 0.001; β = 0.102, p < 0.001; and β = 0.235, p < 0.001 respectively). Pertaining to their future impact, these same three variables were significant predictors at 99% confidence interval (β = 0.419, p < 0.001; β = 0.091, p < 0.001; and β = 0.227, p < 0.001 respectively). The regression results were mostly similar. However, the amount of industry research expenditure was a significant predictor of future licensing income at 95% confidence interval (β = 0.038, p < 0.049).

Patents Applied

The independent variables predicted a very good proportion of variance in current and future patents applied (R^2 = 0.745, F = 1758.360, p < 0.001, N = 3010; and R^2 = 0.737, F = 1435.974, p < 0.001, N = 2574 respectively). Pertaining to their current impact, all independent variables – the number of full time technology transfer staff, other full time support staff, regional concentration of industry R&D professionals, amount of Federal research expenditure, and the amount of industry research expenditure – were significant predictors at 99% confidence interval (β = 0.299, p < 0.001; β = 0.269, p < 0.001; β = 0.052, p < 0.001, β = 0.289, p < 0.001, and β = 0.094, p < 0.001 respectively). These same five variables had significant future impact at 99% confidence interval (β = 0.285, p < 0.001; β = 0.266, p < 0.001; β = 0.046, p < 0.001, β = 0.300, p < 0.001, and β = 0.097, p < 0.001 respectively). The regression results on current and future impact were very similar.

Patents Issued

The independent variables also predicted a very good proportion of variance in current and future patents applied ($R^2 = 0.618$, $F = 922.315$, $p < 0.001$, $N = 2855$; and $R^2 = 0.605$, $F = 767.556$, $p < 0.001$, $N = 2510$ respectively). Pertaining to their current impact, all independent variables – the number of full time technology transfer staff, other full time support staff, regional concentration of industry R&D professionals, amount of Federal research expenditure, and the amount of industry research expenditure – were significant predictors at 99% confidence interval ($\beta = 0.226$, $p < 0.001$; $\beta = 0.223$, $p < 0.001$; $\beta = 0.035$, $p < 0.001$, $\beta = 0.268$, $p < 0.001$, and $\beta = 0.166$, $p < 0.001$ respectively). Pertaining to their future impact, these same five variables were also significant predictors at 99% confidence interval ($\beta = 0.218$, $p < 0.001$; $\beta = 0.217$, $p < 0.001$; $\beta = 0.046$, $p < 0.001$, $\beta = 0.269$, $p < 0.001$, and $\beta = 0.167$, $p < 0.001$ respectively). The results on current and future impact were very similar; and very similar to the regression results for patents applied.

Start Ups Formed

The independent variables predicted a fair proportion of variance in current and future patents applied ($R^2 = 0.396$, $F = 271.334$, $p < 0.001$, $N = 2072$; and $R^2 = 0.418$, $F = 269.989$, $p < 0.001$, $N = 1872$ respectively). Pertaining to their current impact, the number of full time technology transfer staff, other full time support staff, amount of Federal research expenditure, and the amount of industry research expenditure were significant predictors at 99% confidence interval ($\beta = 0.174$, $p < 0.001$; $\beta = 0.208$, $p < 0.001$; $\beta = 0.198$, $p < 0.001$, and $\beta = 0.138$, $p < 0.001$ respectively). Pertaining to their future impact, these same four variables were significant predictors at 99% confidence interval ($\beta = 0.152$, $p < 0.001$; $\beta = 0.240$, $p < 0.001$; $\beta = 0.205$, $p < 0.001$, and $\beta = 0.143$, $p < 0.001$ respectively). Likewise, the regression results on current and future impact were very similar.

Discussion and Conclusion

Summary

In response to the research question, the study demonstrates the quantitative effects of university characteristics and regional industry R&D activities on university technological innovation and commercialization. The findings verify previous studies in the literature. University technology transfer staff, and hence, technology transfer offices (Chang et al., 2006; Foltz et al., 2000; Lach & Schankerman, 2004; Link & Siegel, 2005; Rogers et al., 2000; Thursby et al., 2001), regional R&D industry activities, and hence, proximity to high technology industry firms (Friedman & Silberman, 2003), as well as government (Foltz et al., 2000; O’Shea et al., 2005) and industry financial support (Friedman & Silberman, 2003; Lach & Schankerman, 2004; Link & Siegel, 2005; Rogers et al., 2000; Thursby & Kemp, 2002), facilitate stronger university innovation output and technology commercialization. In addition to the existing literature, this study showed that all these variables also predict future university innovation output and technology commercialization, with the exception of regional industry R&D activities, that only predicted future patents filed and issued. Furthermore, their impact, where significant, are similar between current and future innovation output and commercialization.

The descriptive analyses show that the level of university R&D is increasing, evidenced by their increasingly larger technology transfer offices, and resulting in a correspondingly increasing number of patents filed. However, despite their significance in predicting university innovation output and commercialization, the number of patents issued, licensing income, and start ups formed remained largely the same throughout the period. This verifies the existing finding that growth in successfully university innovation commercialization continues to be slow today (Swamidass & Vulasa, 2009). Furthermore, even though the average annual returns on industry R&D funding (based on licensing income alone) are much better than that for government R&D funding, the trends suggest that both sources of R&D funding have not increased substantially.

Theoretical Contributions

This study addresses the two theoretical gaps by verifying findings in the literature and enriching our understanding of what drives university innovation and commercialization in the process. Pertaining to the first gap, the predictive models include drivers comprising both university characteristics and regional industry R&D activities as potential drivers at the same time. The five independent variables included in this study had significant positive relationships with the dependent variables.

The concentration of regional industry R&D activities was not a significant predictor of current and future university licensing income as well as start up formation. This is contrary to the literature that posits the positive influence of proximity to R&D companies (Friedman & Silberman, 2003). It is plausible that the operationalization of a university's proximity to industry R&D activities can be enhanced. Using the state level measure may be insufficient to accurately capture proximity. In Friedman and Silberman's (2003) study, an established composite measure index of high technology activities (albeit only in 2003) at the MSA level was used. This composite measure also included measures such as venture capital and high technology firms among others. However, it was not available for all years from 1991 to 2014 and given resource limitations, I was not able to use the same measure for the entire period. Nonetheless, its significance in driving patents applied and issued suggests that this is a relevant factor that can be included in future investigations with an enhanced measurement.

The second theoretical gap pertains to the investigation on future impact. Many of independent variables were found to be significant predictors in both current and future university innovation output and technology commercialization to various degrees; with the exception of regional high technology R&D activities and industry research funding, which did not predict current licensing income and start up formation, and licensing income respectively. Within limitations of measuring industry R&D activities as discussed, these findings verify previous findings pertaining to government financial support (Foltz et al., 2000; O'Shea et al., 2005), industry funding (Friedman & Silberman, 2003; Lach & Schankerman, 2004; Link & Siegel, 2005; Rogers et al., 2000; Thursby & Kemp, 2002), proximity to high technology industry activities (Friedman & Silberman, 2003), and technology transfer offices transfers (Chang et al., 2006; Foltz et al., 2000; Lach & Schankerman, 2004; Link & Siegel, 2005; Rogers et al., 2000; Thursby et al., 2001). As a timely revisit of the literature, this study also demonstrates future impact, thus enriching our knowledge. The similarity between coefficients of current and future impact suggests that these variables continue to be important in future and should not be overlooked for temporary gain. Theoretically, they also warrant further investigations in future models.

The insignificant future impact from regional high technology R&D activities could also be due to the measurement limitation. Interestingly, although industry research funding has a better return on investments, it is not a significant predictor of future licensing income. This must be interpreted with caution. Future studies can break down and control the types of industry funding by subject area, so as to investigate how and when it can influence future licensing income.

Implications and Other Future Research

Technological innovation is a key driver of economic growth (European Commission, 2008; OECD, 2013; Romer, 1990). As sources of innovation (Friedman & Silberman, 2003), the economic importance of university innovation cannot be ignored. Universities, with strong industry R&D linkages, are the impetus of high technology industry clusters (Florida et al., 2006) that have higher economic productivity (DeVol et al., 2016). The consistent increase in university R&D activities from 1991 to 2014 did not occur with corresponding increases in innovation output and commercialization. Yet, university characteristics and regional industry R&D activities drive innovation output and commercialization. Incidentally, returns generated from government R&D funding were less efficient than industry R&D funding, implying that governments can better allocate existing R&D resources to universities through better R&D policies. Also, universities can engage in better management practices to utilize R&D resources. For instance, the average sizes of technology transfer offices have consistently increased. However, these have only translated to a higher average number of patents filed, but not patents issued; neither did they facilitate higher licensing income and start up formation. Future studies can also control government R&D funding by subject area to explore differences in efficiencies.

The high returns from industry R&D funding and their significant current and future impact suggest that universities may increase their exploration of industry sources for support. Its significant impact on future but not current licensing income suggests that industry funding is a long-term undertaking that may not see immediate gains. However, the findings also show that regional R&D activities did not influence current and future startup company formation. This could again be the result of the state level measure as a proxy for industry R&D activities. Future studies could therefore use a more geographically specific and broader measure for accuracy. In addition, longer-term measurements of future impact, such as a three- or five-year lag, may enrich our understanding further.

The AUTM data set is not a balanced time series data set, since it was based on a survey and not every university in the U.S. was surveyed in every year (1991 to 2014). While the data set is sufficiently comprehensive for analysis, an updated and more complete data set would provide a clearer picture on trends, as well as longer-term measurements of future impact. Finally, future studies can also enrich the measurement of university innovation by looking at citations. Not every university R&D project results in patents. Some result in academic publications that are cited to various degrees. Furthermore, using regional economic data at the MSA or county level, future studies can also explore the economic impact of university technological innovation and commercialization.

REFERENCES

Anderson, T. R., Daim, T. U., & Lavoie, F. F. (2007). Measuring the efficiency of university technology transfer. *Technovation*, *27*(5), 306–318.

Bauer, S. M., & Flagg, J. L. (2010). Technology Transfer and Technology Transfer Intermediaries. *Assistive Technology Outcomes and Benefits*, *6*(1), 129–150.

Brynjolfsson, E., & Yang, S. (1996). Information technology and productivity: a review of the literature. *Advances in Computers*, *43*, 179–214.

Carlsson, B., & Fridh, A.-C. (2002). Technology transfer in United States universities. *Journal of Evolutionary Economics*, *12*(1–2), 199–232.

Chang, Y.-C., Chen, M.-H., Hua, M., & Yang, P. Y. (2006). Managing academic innovation in Taiwan: Towards a “scientific–economic” framework. *Technological Forecasting and Social Change*, *73*(2), 199–213.

Chapple, W., Lockett, A., Siegel, D., & Wright, M. (2005). Assessing the relative performance of UK university technology transfer offices: parametric and non-parametric evidence. *Research Policy*, *34*(3), 369–384.

DeVol, R., Lee, J., & Ratnatunga, M. (2016). *2016 State Technology and Science Index. Sustaining America’s Innovation Economy*. Santa Monica, CA: Milken Institute.

European Commission. (2008). *Knowledge for Growth European Issues and Policy Challenges* (No. EUR 23725 EN).

Florida, R. (1999). The role of the university: leveraging talent, not technology. *Issues in Science and Technology*, *15*(4), 67–73.

Florida, R., Gates, G., Knudsen, B., & Stolarik, K. (2006). *The University and the Creative Economy*. USA: Heinz Endowments.

Foltz, J., Barham, B., & Kim, K. (2000). Universities and agricultural biotechnology patent production. *Agribusiness*, *16*(1), 82–95.

Friedman, J., & Silberman, J. (2003). University technology transfer: do incentives, management, and location matter? *The Journal of Technology Transfer*, *28*, 17–30.

Ho, M. H.-C., Liu, J. S., Lu, W.-M., & Huang, C.-C. (2014). A new perspective to explore the technology transfer efficiencies in US universities. *The Journal of Technology Transfer*, *39*, 247–275.

Hsu, D. W., Shen, Y.-C., Yuan, B. J., & Chou, C. J. (2015). Toward successful commercialization of university technology: Performance drivers of university technology transfer in Taiwan. *Technological Forecasting and Social Change*, *92*, 25–39.

Ion, P., & Cristina, V. (2014). Innovation: a strategic option for future economic growth. *Annals of the University of Oradea*, *23*(1), 1220–1225.

Kauffman, R. J., & Weill, P. (1989). An evaluative framework for research on the performance effects of information technology investment. *Information Systems Working Papers Series, Vol.*

Lach, S., & Schankerman, M. (2004). Royalty sharing and technology licensing in universities. *Journal of the European Economic Association*, *2*(2-3), 252–264.

Leigh, R. (1970). The Use of Location Quotients in Urban Economic Base Studies. *Land Economics*, *46*(2), 202–205. https://doi.org/10.2307/3145181

Link, A. N., & Siegel, D. S. (2005). Generating science-based growth: an econometric analysis of the impact of organizational incentives on university–industry technology transfer. *European Journal of Finance*, *11*(3), 169–181.

Lockett, A., & Wright, M. (2005). Resources, capabilities, risk capital and the creation of university spin-out companies. *Research Policy*, *34*(7), 1043–1057.

Mansfield, E. (1991). Academic research and industrial innovation. *Research Policy*, *20*(1), 1–12.

Markman, G. D., Gianiodis, P. T., Phan, P. H., & Balkin, D. B. (2005). Innovation speed: Transferring university technology to market. *Research Policy*, *34*(7), 1058–1075.

Mathews, J. A., & Hu, M.-C. (2007). Enhancing the role of universities in building national innovative capacity in Asia: the case of Taiwan. *World Development*, *35*(6), 1005–1020.

Mowery, D. C., & Sampat, B. N. (2005). The Bayh-Dole act of 1980 and university-industry technology transfer: a model for other OECD governments? In *Essays in honor of Edwin Mansfield* (pp. 233–245). Springer.

OECD. (2013). *Innovation-driven Growth in Regions: The Role of Smart Specialisation*. Retrieved from http://www.oecd.org/sti/inno/smart-specialisation.pdf

O'Shea, R. P., Allen, T. J., Chevalier, A., & Roche, F. (2005). Entrepreneurial orientation, technology transfer and spinoff performance of US universities. *Research Policy*, *34*(7), 994–1009.

Oz, E. (2005). Information technology productivity: in search of a definite observation. *Information & Management*, *42*(6), 789–798.

Powers, J. B., & McDougall, P. P. (2005). University start-up formation and technology licensing with firms that go public: a resource-based view of academic entrepreneurship. *Journal of Business Venturing*, *20*(3), 291–311.

Rhoten, D., & Calhoun, C. (2011). *Knowledge matters: The public mission of the research university*. Columbia University Press.

Rogers, E. M., Yin, J., & Hoffmann, J. (2000). Assessing the effectiveness of technology transfer offices at US research universities. *The Journal of the Association of University Technology Managers*, *12*(1), 47–80.

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy*, *98*(5), 71–102.

Siegel, D. S., & Phan, P. (2005). Analyzing the effectiveness of university technology transfer: implications for entrepreneurship education. *Advances in the Study of Entrepreneurship, Innovation, and Economic Growth*, *16*(1), 1–38.

Siegel, D. S., Veugelers, R., & Wright, M. (2007). Technology transfer offices and commercialization of university intellectual property: performance and policy implications. *Oxford Review of Economic Policy*, *23*(4), 640–660.

Siegel, D. S., Waldman, D., & Link, A. (2003). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study. *Research Policy*, *32*(1), 27–48.

Siegel, D., Wright, M., Chapple, W., & Lockett, A. (2008). Assessing the relative performance of university technology transfer in the US and UK: a stochastic distance function approach. *Econ. Innov. New Techn.*, *17*(7–8), 717–729.

Stiroh, K. (2002). Are ICT Spillovers Driving the New Economy. *Review of Income and Wealth*, *48*, 33–57.

Swamidass, P. M., & Vulasa, V. (2009). Why university inventions rarely produce income? Bottlenecks in university technology transfer. *The Journal of Technology Transfer*, *34*(4), 343–363.

Thursby, J. G., Jensen, R., & Thursby, M. C. (2001). Objectives, characteristics and outcomes of university licensing: A survey of major US universities. *The Journal of Technology Transfer*, *26*(1–2), 59–72.

Thursby, J. G., & Kemp, S. (2002). Growth and productive efficiency of university intellectual property licensing. *Research Policy*, *31*(1), 109–124.

Thursby, J. G., & Thursby, M. C. (2002). Who Is Selling the Ivory Tower? Sources of Growth in University Licensing. *Management Science*, *48*(1), 90–104. https://doi.org/http://dx.doi.org/10.1287/mnsc.48.1.90.14271

Wright, M., Vohora, A., & Lockett, A. (2004). The formation of high-tech university spinouts: the role of joint ventures and venture capital investors. *The Journal of Technology Transfer*, *29*(3–4), 287–310.